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INVENTORY OF PCBs IN POLE TOP TRANSFORMERS

Report No 91-196-K

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ABSTRACT

The inventory and distribution of PCBs in a number of PCB contaminated pole top transformers were measured. The transformers varied in make, size and kVA ratings. Their bulk oil contamination levels ranged between 34 and 1790 ppm. About 95 % of the PCB inventory in the drained units resided within the porous insulation with the balance being associated with the nonporous metallic surfaces. The total PCB inventory was observed to be linearly related to the product of the bulk oil contamination level and the weight of the drained transformer. The PCB in the porous insulation, associated principally with absorbed oil, was also observed to be linearly related to the bulk oil contamination level. The adsorbed PCBs on the steel surfaces followed a Freundlich adsorption isotherm.

job	file	date	report no.
32-510-100	837.34	November 22, 1991	91-196-K

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EXECUTIVE SUMMARY

INVENTORY OF PCBs IN POLE TOP TRANSFORMERS

A. Husain and R. Mowat

Ontario Hydro has a large number (about 300,000) of pole-top transformers of different sizes distributed in the Province. The mineral oil contained in these transformers is contaminated with PCBs. While most of the units have a PCB level of less than 50 ppm, about 10% of the units contain PCBs in excess of 50 ppm. Transformers with less than 50 ppm PCBs are categorized as PCB-free while those exceeding 50 ppm are considered contaminated.

The presence of PCBs in the transformers requires that scrapped PCB contaminated units be disposed of in an environmentally appropriate manner. Currently, disposal of such transformers follows an interim guideline issued by the MOE in 1986. Under that guideline equipment containing less than 2500 L of oil with between 50 and 500 ppm PCB is considered to be decontaminated when all free liquid is removed, the unit allowed to stand for a minimum of 24 h and any additional free liquid accumulation removed. Accordingly, pole top transformers with 50-500 ppm contamination are drained at Area and District Service Centres before being shipped to Kipling for disposal for their scrap metal value, while those exceeding 500 ppm are stored 'as is' or after draining at the Service Centres. Pole top transformers with <50 ppm contamination are drained locally or sent to the Kipling facility for draining and are then disposed.

The interim MOE guideline was issued in 1986 on the understanding that formal decontamination guidelines then under development would be issued. These formal guidelines were never issued and in mid 1990 it was learnt that previous permissions to drain and decontaminate small equipment might be rescinded in the future. The MOE's position appears to be that current methods of decontamination are not sufficiently effective for nonhazardous waste disposal. The porous insulation materials and wood in the cores remain PCB contaminated and thus constitute PCB waste. Accordingly, MOE may in future disallow the current disposal practice for small equipment. In the absence of an approved decontamination method, the net impact of MOE's ruling would be a significant increase in PCB solid waste requiring storage.

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A research program to develop decontamination procedures was already underway at the time MOE's proposed new ruling was learnt of. The focus of the program, which initially was to address the >500 ppm category of transformers, was therefore expanded to include the 50 to 500 ppm population. The first phase of the program involved a detailed assessment of the PCB inventory in pole-top transformers while decontamination of transformers was addressed in the second phase. This report documents the results obtained in Phase 1.

Each transformer was completely dismantled into its various components. Samples of porous materials were extracted in isooctane using Soxhlet extraction units. The extract was analysed for PCBs using gas chromatography. The nonporous surfaces were swiped with isooctane wetted Kimwipes which were then extracted in isooctane for analysis.

The detailed inventory assessment indicated that while the various insulations represent 3.7 $\pm$ 0.7 % of the transformer weight, they house 94.8 $\pm$ 2.9 % of the total PCB inventory. The balance of the PCB is associated with the nonporous metallic surfaces. About 55 to 70 % of the inventory is associated with papers and 10 to 20 % with pressboards. The PCB in the porous insulation is principally associated with absorbed oil.

The total inventory of PCBs in the transformers varied between 0.04 g for the 'uncontaminated' 34 ppm transformer to 1.04 g for the transformer with 1790 ppm contamination. These quantities exclude the PCBs associated with the oil pool found at the bottom of the casings. Accounting for the latter increases the total inventory of the drained transformers by up to 70 wt %.

An excellent correlation was obtained between the overall contamination level expressed as the ratio (weight of PCB to weight of the undismantled drained transformer) and the bulk oil contamination level despite the fact that the transformers examined differed in several respects : year of manufacture, manufacturer, size and kVA rating. This relationship can, therefore, be used to estimate the amount of residual PCB present in a drained transformer provided the weight of the transformer and the bulk oil contamination level are known.

The average contamination in the porous materials was observed to be linearly related to the bulk oil contamination level. According to this relationship, porous materials dismantled from transformers with bulk oil contamination level less than 245 ppm would constitute non-PCB waste, i.e. less than 50 ppm contamination. This could be the basis for requesting MOE to allow the continuation of the current decontamination practice for transformers with fluid contamination levels up to about 250 ppm; those above this level would require decontamination to reduce the PCB content of porous materials below 50 ppm.

The average contamination level (ug/100cm^2) on transformer steel surfaces (excluding the lid and bottom of casing) conformed to the Freundlich adsorption isotherm and was given by $8.71\ 10^{-3} * C_b^{\ 1.05}$ where C_b denotes the bulk oil contamination (ug/g) level. According to the relationship, a surface contamination of 10 ug/100 cm^2 corresponds to a fluid

contamination level of about 800 ppm. Compared to their cylindrical surfaces, the contamination level on casing bottoms was much higher, while the lid had lower contamination.

The swiping efficiency, usually assumed to be unity, was found to have a value of 0.57 for core steel. Similar determinations for other metallic surfaces should be performed. Neglecting to account for the swiping efficiency can potentially lead to the release of materials above the regulatory guideline.

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To

Mr. D.A. Lee
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INVENTORY OF PCBs IN POLE TOP TRANSFORMER

A. Husain and R. Mowat

1.0 INTRODUCTION AND BACKGROUND

Ontario Hydro has a large number (about 300,000) of pole-top transformers of different sizes distributed in the Province. The mineral oil contained in some of these transformers is contaminated with PCBs. While most of the units have a PCB level of less than 50 ppm, about 10% of the units contain PCBs in excess of 50 ppm /1/. Transformers with less than 50 ppm PCBs are categorized as PCB-free while those exceeding 50 ppm are considered to be contaminated.

The presence of PCBs in the transformers requires that scrapped PCB contaminated units be disposed of in an environmentally appropriate manner. Currently, disposal of such transformers follows an interim guideline issued by the MOE in 1986 /2/. Under that guideline equipment containing less than 2500 L of oil with between 50 and 500 ppm PCB is considered to be decontaminated when all free liquid is removed, the unit allowed to stand for a minimum of 24 h and any additional free liquid accumulation removed. Accordingly, pole top with 50-500 ppm contamination are drained at Area and District Service Centres before being shipped to Kipling for disposal for their scrap metal value, while those exceeding 500 ppm are stored 'as is' or after draining at the Service Centres. Pole top transformers with <50 ppm contamination are drained locally or sent to the Kipling facility for draining and are then disposed.

Drained transformer carcasses are disposed of as scrap for their metal recovery value. At the scrap yard, any additional fluid accumulations are removed, the casings compacted and shredded for melting and reuse, the core steel manually separated and shredded for melting and reuse and the coil incinerated to burn off insulation for the recovery of valuable copper windings.

The interim MOE guideline was issued in 1986 on the understanding that formal decontamination guidelines then under development would be issued. These formal guidelines were never issued and in mid 1990 it was learnt that previous permissions to drain and decontaminate small equipment might be rescinded in the future. The MOE's position appears to be that current methods of decontamination are not sufficiently effective for nonhazardous waste disposal. The porous insulation materials and wood in the cores remain PCB contaminated and thus constitute PCB waste. Accordingly, MOE may in future disallow the current disposal practice for small equipment. In the absence of an approved decontamination method, the net impact of MOE's ruling would be a significant increase in PCB solid waste requiring storage.

A research program to develop decontamination procedures (the need for developing this technology was identified in a recent PCB Destruction Task Group report /3/) was already underway at the time MOE's proposed new ruling was learnt of. The focus of the program which initially was to address the >500 ppm category of transformers was expanded, therefore, to include the 50 to 500 ppm population.

Previous work at OHRD /4-7/ focussed mostly on the decontamination of askarel filled transformers and capacitors; the solvents examined included No. 2 fuel oil and trichloroethylene. Cleaning of PCB contaminated transformers was only briefly investigated. A 15 kVA transformer containing insulating oil with a PCB concentration of 150 ppm was autopsied: drainage removed 98% of the oil and associated PCBs; a subsequent trichloroethylene wash of the core removed 98 % of the PCBs remaining after drainage.

A recent EPRI report /8/ described the results of a comprehensive assessment of the PCB inventory in contaminated pole-top transformers. Three oil-filled transformers containing 130, 275 and 430 ppm PCB, respectively, were drained and dismantled to determine the detailed inventory of PCBs in the various materials of the transformers. The oil and PCB content of the various insulations were determined by solvent extraction while the surface PCB contamination of various non-porous metallic surfaces was determined by a combination of surface swiping and solvent extraction. The various cellulosic insulations typically contained about 30 wt % oil which was 10-15 % richer in PCBs than the corresponding bulk oil. The detailed inventory indicated that about 95 % of the PCBs was associated with the removable oil; the balance resided in the various insulations and on the non-porous surfaces.

In the EPRI study, the reliability of the PCB distribution measurements was further assessed by draining three transformers with oil contamination levels of 235, 337 and 365 ppm PCBs, respectively, and refilling them with fresh oil; the PCB content in the new oil was monitored with time. The transformer with the initial contamination of 235 ppm was energized without loading to excite the core and provide vibration; in this case, the equilibrium PCB concentration was achieved within a day. That with 337 ppm contamination was left to stand at room temperature; equilibrium was achieved within 60 days. The last transformer, loaded to reach a temperature of 80 deg C, achieved equilibration within one day. In all

cases, the equilibrium level achieved in the refilled transformer corresponded to 5-6 % of the original PCB inventory in the transformer consistent with the results of the autopsies obtained earlier. The EPRI study clearly demonstrated the feasibility of reclassifying transformers by a drain and soak procedure.

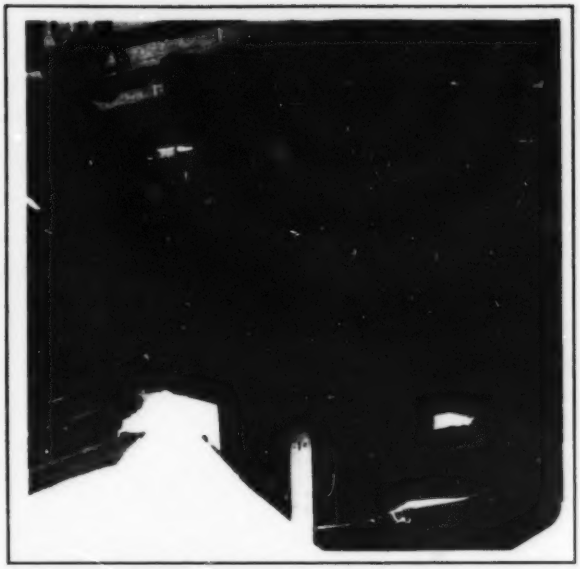
The present study, similar to the EPRI study, has a two-fold objective: 1) develop a detailed assessment of the PCB inventory in pole-top transformers with contamination levels up to 2000 ppm, and 2) investigate the decontamination of transformers using oil. The choice of oil as the decontamination fluid is based on the availability of Ontario Hydro's sodium based decontamination facility to treat the resulting waste oil. This report documents the results obtained in support of the first objective; the results of decontamination will be reported separately /9/.

2.0 EXPERIMENTAL

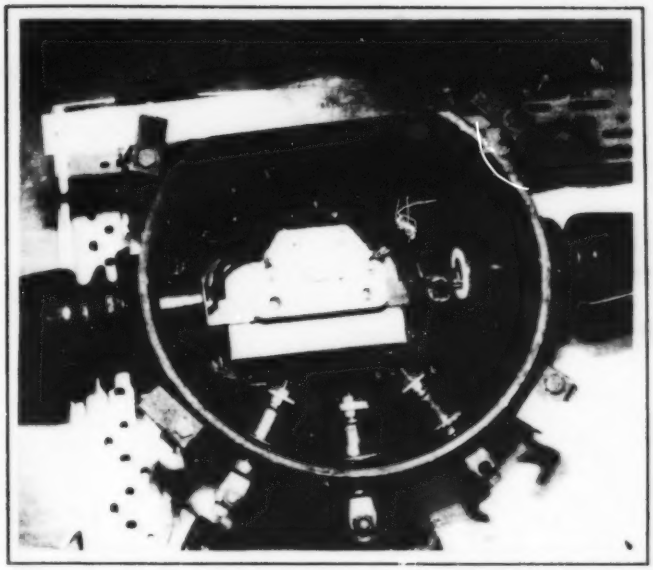
Characteristics of the transformers investigated are shown in Table 1. The first set of data under Column 4 refers to analysis of oil samples drawn from the filled transformers in the field while the second set (in brackets) were obtained upon re-analysis of samples from the oil pool at the bottom of the casings (the transformers were drained in the field before being shipped to the laboratory). Hereafter, reference to individual transformers in the text is based on the second data set.

Following the removal of the small quantity of accumulated oil at the bottom of the casing, each transformer was completely dismantled into its various components. Figure 1 illustrates a transformer in its various stages of dismantlement.

Samples of porous materials were extracted in isooctane using Soxhlet extraction units. Weight loss of the samples following extraction and subsequent drying was attributed to absorbed oil in the sample (dissolution of glues, plasticizers etc. present in some of the materials would over-estimate the amount of absorbed oil). The extract containing the desorbed oil and associated PCBs was adjusted with additional isooctane to 1 wt % oil and then analysed for PCBs using gas chromatography. Extractions were performed typically for about 10 h to ensure the near complete removal of the contaminant. This was established by performing a second extraction of a limited set of materials from the 215 and 1790 ppm transformers in the more polar solvent, methylene chloride. The additional PCB released in the second extraction was relatively small (< 2 %) except in the case of a wood (W1) and a plastic (PL1) sample from the 1790 ppm transformer; in these cases the additional releases amounted to 20 % of the PCB inventory in the materials.

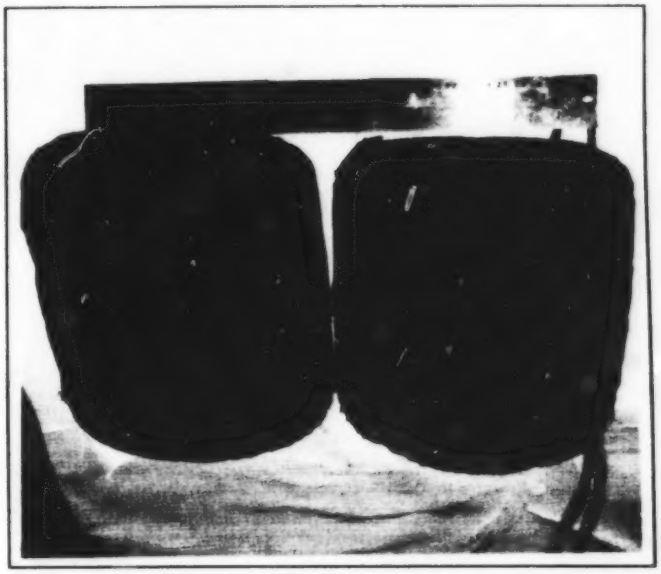


(a) As received pole top transformer



(b) Top internal view of transformer

(c) Removed transformer core and winding assembly



(d) Winding coils

FIGURE 1

DISASSEMBLY OF A TYPICAL POLE TOP TRANSFORMER

201135-K19-RD

TABLE 1

TRANSFORMERS INVESTIGATED

SERIAL NO.	MAKE	KVA	PCB (PPM)*	PCB TYPE
80030-55	FED/PIONEER	25	53 (34)	1242
5612-43	FED/PIONEER	50	180 (177)	1254
705263	WESTINGHOUSE	5	220 (215)	1242
54252	SUPREME	5	1180 (1180)	1260
54023	SUPREME	5	1540 (1790)	1260

* Units of ug/g;

Samples of core steel and other sheet metal surfaces were swiped three times using isooctane wetted Kimwipes (the background PCB levels in Kimwipe paper was negligible). These Kimwipes were then immersed in isooctane contained in glass vials. The vials were placed in an ultrasonic bath for short durations, following which the extract was decanted and replaced with fresh solvent. Each set of Kimwipes was thus extracted in three batches of fresh solvent. The pooled extract was boiled down and adjusted to 1 wt% oil using fresh Voltesso 35 oil and then analysed for PCBs.

Copper windings were not swiped for practical reasons. Instead, samples were decontaminated in an ultrasonic bath using isooctane. The procedure followed was similar to that for the Kimwipes. An attempt was made to dissolve the varnish on the windings using hot KOH to assess if PCBs penetrated the coating. Partial loosening of the coating was experienced; however, no additional significant release of PCBs was measured.

3.0 RESULTS

Detailed results for the transformers are summarised in Tables 2-6. Each Table lists the distribution of weight in the transformer, the contamination levels on the various metal surfaces and the oil and PCB content of the porous materials (any residual PCB in the materials following extraction in isooctane was disregarded). The PCB content in the porous material is expressed in two ways: 1) as micrograms per gram of the oil-soaked material and 2) as the ratio of PCB to oil in the material. The former is useful for assessing waste management and decontamination options while the latter indicates the degree of partitioning of the contaminant between the porous materials and the bulk oil phase.

Results in Tables 2-6 indicate the following:

1. The oil content of porous materials from the first three transformers (34, 177 and 215 ppm PCB in bulk oil, respectively) typically varied between 20 to 40 wt% compared to about 20 wt% in materials from the 1180 and 1790 ppm transformers.

2. The porous materials from the 34 ppm transformer had contamination levels ranging up to 21 ppm (see second last column in Table 2) well within the 50 ppm threshold for contaminated transformers. Materials from the higher contaminated (177 - 1790 ppm) transformers generally had PCB levels exceeding 50 ppm; thus scrapped transformers with up to 500 ppm fluid contamination levels which are currently being released following drainage do infact contain porous materials exceeding the regulatory 50 ppm limit.

3. The PCB/oil ratio (ug/g) for the porous materials from each transformer was generally similar (within experimental error) to the corresponding PCB concentration in the bulk fluid indicating little or no preferential partitioning of the PCBs in the porous materials. However, there were a few exceptions where the ratio was significantly lower and others where it was significantly higher than the bulk contamination level. Among these exceptions, the most notable were the plastic wire insulation from the 1180 and 1790 ppm transformers; these were, respectively, 26 and 6 times higher than the corresponding bulk fluid level.

4. The contamination on the non-porous surfaces of the 34, 177 and 215 ppm transformers was less than the generally accepted threshold of 10 ug/100 cm^2. However, PCB contamination on the surfaces of the 1180 and particularly the 1790 ppm transformers significantly exceeded this threshold value.

Casing contamination levels in Tables 2-6 refer to their vertical cylindrical surfaces. These were generally lower than measurements on their bottom surfaces (an attempt was made to completely drain any residual oil present on the bottom of the casings prior to swiping). In particular, the 1180 ppm transformer which appeared to have failed by arcing (metal surfaces were partially discoloured) had a considerable amount of residue at the bottom (about 220 times as contaminated as the cylindrical surfaces). Table 7 summarises these variations along with measurements of the internal lid surfaces. Note that the internal lid surfaces had significant contamination levels despite being above the operating oil level in the transformers. However, these levels were generally lower than on the immersed casing surfaces.

TABLE 2

RESULTS OF SURFACE SWIPINGS AND SOLVENT EXTRACTION FOR MATERIALS FROM TRANSFORMER # 80030-55

(Bulk Oil Contamination Level 34 ppm)

ID	DESCRIPTION	WEIGHT (g)	PCB SURFACE CONTAMINAT. (ug/100 cm^2)	OIL CONTENT IN SOLID (%)	PCB IN SAMPLE (PPM)*	PCB/OIL (PPM)+
M1	CORE STEEL	70909	0.21			
M2	COPPER WINDING	9300	1.39			
M3	ALUMINIUM SHEET	7273	0.62			
M4	STEEL	4457	0.77			
M5	STEEL STRAP	177	0.34			
M9	CASING	18636	0.21			
M10	LID	3504				
PR1	FOUR STRIPS	383		20.71	7.1	34.1
PR2	BOX LIKE PIECE	186		40.53	15.8	39.0
PR3	IRREGULAR SHAPED PIECE	76		27.08	9.0	33.1
PR4	TWO FOLDED RECTANG.PIECES	313		29.73	10.5	35.2
PA1	GREEN PAPER STRIPS	124		24.89	8.6	34.7
PA2	FIVE FLATTENED ROLLS	244		41.42	9.3	22.5
PA3	GREEN STRIPS	95		28.19	10.6	37.6
PA4	GREEN, SEPARATED ALUMINIUM	745		27.43	11.9	43.5
PA5	GREEN, SEPARATED ALUMINIUM	430		32.02	9.6	30.0
PA6	BROWN	461		31.80	9.8	30.9
PA7	BROWN	147		33.56	10.6	31.6
PA8	GREEN, SEPARATED THE COPPER	784		32.27	5.7	17.7
PA9	ASSORTED SCRAPS	25				
C1	CLOTH RIBBON	111		53.18	20.6	38.8
MS1	SIX CORRUGATED PANELS	145		5.43	0.6	11.4
MS2	ASSORTED EXTERNAL PIECES	6136				

* micro-gram PCB per gram of oil-soaked material.

\+ micro-gram PCB per g of oil soaked in sample.

TABLE 3

RESULTS OF SURFACE SWIPINGS AND SOLVENT EXTRACTION FOR MATERIALS FROM TRANSFORMER # 5612-43

(Bulk Oil Contamination Level 177 ppm)

ID	DESCRIPTION	WEIGHT (g)	PCB SURFACE CONTAMINAT. (ug/100 cm^2)	OIL CONTENT IN SOLID (%)	PCB IN MATERIAL (PPM)*	PCB/OIL (PPM)+
M1	CORE STEEL	123182	1.17			
M2	COPPER WINDING	10909	1.56			
M3	ALUMINIUM SHEET	14545	0.52			
M4	STEEL	6351	5.70			
M5	STEEL STRAP	361	1.51			
M9	CASING	26818	0.39			
M10	LID	5503				
PR1	FOUR STRIPS	670		18.0	17.7	98
PR2	BOX LIKE PIECE	305		26.3	43.1	164
PR3	IRREGULAR SHAPED PIECE	148		22.9	47.1	205
PR4	TWO FOLDED RECTANG.PIECES	452		27.6	58.3	212
PA1	FIVE FLATTENED ROLLS	573		37.6	67.3	179
PA2	GREEN STRIPS	356		24.9	41.8	168
PA3	GREEN, SEPARATED ALUMINIUM	1052		27.2	31.3	115
PA4	BROWN	1228		35.3	58.9	167
PA5	GREEN, SEPARATED THE COPPER	892		26.6	41.2	155
PA6	ASSORTED SCRAPS	34		23.8	50.6	212
C1	CLOTH RIBBON	195		51.3	91.5	179
MS1	SIX CORRUGATED PANELS	255		2.8	3.0	107
MS2	ASSORTED EXTERNAL PIECES	9493				

* micro-gram PCB per gram of oil-soaked material.

\+ micro-gram PCB per g of oil soaked in sample.

TABLE 4

RESULTS OF SURFACE SWIPINGS AND SOLVENT EXTRACTION FOR MATERIALS FROM TRANSFORMER # 705263

(Bulk Oil Contamination Level 215 ppm)

ID	DESCRIPTION	WEIGHT (g)	PCB SURFACE CONTAMINAT. (ug/100 cm^2)	OIL CONTENT IN SOLID (%)	PCB IN MATERIAL (PPM)*	PCB/OIL (PPM)
M1	CORE STEEL	23182	2.27			
M2	COPPER WINDING (thick)	3013	0.40			
M3	COPPER WINDING (thin)	3762	0.87			
M4	STEEL PIECE	693	3.75			
M5	STEEL PIECE	300	1.14			
M6	ASSORTED INTERNAL PIECES	1240	3.99			
M7	STEEL STRAPS	104	3.73			
M9	CASING	14816	1.21			
M10	LID	2398				
PR1	PRESSBOARD	72		19.7	51	256
PR2	PRESSBOARD	283		22.2	60	270
PR3	STRIPS	134		22.0	58	264
PR4	PRESSBOARD	59		2.4	3	100
PA1	WIRE SHEATHING ROLLS	31		45.1	138	305
PA2	GREEN PAPER #1	149		27.8	78	280
PA3	GREEN PAPER #2	326		30.2	79	261
PA4	GREEN PAPER #3	615		30.1	78	259
C1	CLOTH RIBBON	68		45.8	134	293
R1	GASKETS(LID+EXTERNAL)	154		11.2	76	679
MS1	ASSORTED EXTERNAL PIECES	5378				

* micro-gram PCB per gram of oil-soaked material.

\+ micro-gram PCB per g of oil soaked in sample.

TABLE 5

RESULTS OF SURFACE SWIPINGS AND SOLVENT EXTRACTION FOR MATERIALS FROM TRANSFORMER # 54252

(Bulk Oil Contamination Level 1180 ppm)

ID	DESCRIPTION	WEIGHT (g)	PCB SURFACE CONTAMINAT. (ug/100 cm^2)	OIL CONTENT IN SOLID (%)	PCB IN MATERIAL (PPM)*	PCB/OIL (PPM)+
M1	CORE STEEL	23636	5.1			
M2	COPPER WINDING (THIN)	6244	14.2			
M3	COPPER WINDING (THICK)	7120	105.0			
M4	STEEL STRAP	50	15.7			
M5	COIL FRAME ASSEMBLY	2037	17.0			
M9	CASING	13300	19.7			
M10	LID	1800	4.9			
PR1		224		25.0	161	647
PR2		335		8.6	77	890
PA1	BLACK, INSULTD. THIN COPPER	288		12.6	383	3036
PA2	GREEN BRITTEL PAPER	337		16.6	171	975
PA3	BROWN SEPARATING PAPERS	736		21.1	218	1034
C1	REED LIKE TAPE	100		16.4	138	837
W1	SEPARATORS	191		22.7	155	681
W2	TAPE	433		17.3	237	1370
PL1	HARD PAPER/PLASTIC DIVIDERS	170		6.2	30	479
PL2	PLASTIC WIRE INSULATION	15		0.6	180	30612
MS1	ASSORTED EXTERNAL PIECES	4526				
MS2	ASSORTED INTERNAL PIECES	834				

* micro-gram PCB per gram of oil-soaked material.

\+ micro-gram PCB per gram of oil soaked in sample.

TABLE 6

RESULTS OF SURFACE SWIPINGS AND SOLVENT EXTRACTION FOR MATERIALS FROM TRANSFORMER # 54023
(Bulk Oil Contamination Level 1790 ppm)

ID	DESCRIPTION	WEIGHT (g)	PCB SURFACE CONTAMINAT. (ug/100 cm^2)	OIL CONTENT IN SOLID (%)	PCB IN MATERIAL (PPM)*	PCB/OIL (PPM)+
M1	CORE STEEL	23636	12.9			
M2	COPPER WINDING (THIN)	9091	95.8			
M3	COPPER WINDING (THICK)	3587	59.8			
M4	STEEL STRAP	49	29.2			
M5	COIL FRAME ASSEMBLY	2442	30.6			
M9	CASING	20000	112.0			
M10	LID	1870	20.5			
PR1		224		24.4	245	1005
PR2		297		7.6	99	1297
PR3		38		14.2	266	1865
PA1	BLACK, INSULTD. THIN COPPER	288		15.8	675	4303
PA2	GREEN BRITTEL PAPER	337		15.9	181	1135
PA3	BROWN SEPARATING PAPERS	736		19.2	446	2319
C1	REED LIKE TAPE	100		16.3	277	1704
W1	SEPARATORS	191		16.6	167	989
W2	TAPE	433		18.2	444	2446
PL1	HARD PAPER/PLASTIC DIVIDERS	170		6.6	37	574
PL2	PLASTIC WIRE INSULATION	15		4.0	464	11507
MS1	ASSORTED EXTERNAL PIECES	4585				
MS2	ASSORTED INTERNAL PIECES	834				

* micro-gram PCB per gram of oil-soaked material.

\+ micro-gram PCB per gram of oil soaked in sample.

TABLE 7

SURFACE CONTAMINATION OF CASING

PCB IN BULK OIL	CONTAMINATION (ug/100 cm^2)		
		CYLINDRICAL	
(ppm)	BOTTOM	SURFACES	LID
34	5	0.15	-
180	192	0.39	-
215	74	1.20	-
1180	4300	20	5
1790	-	112	21

The average contamination on all steel surfaces (excluding the lid and bottom of casing) for each transformer is shown in Table 8. Its dependence on the bulk oil level is clearly evident. The data can reasonably well be described by a Freundlich type of adsorption isotherm characterized by the equation:

$$C_s = k\, C_b^{\,n}$$

where C_s and C_b denote the surface contamination (ug/100 cm^2) and bulk oil contamination (ug/g) levels, respectively. Fit of the data to the above equation yielded values of $8.71\ 10^{-3}$ and 1.05 for the constants k and n, respectively.

TABLE 8

AVERAGE CONTAMINATION LEVEL ON STEEL SURFACES AND FIT TO FREUNDLICH ADSORPTION ISOTHERM

PCB IN BULK OIL	AVG. SURFACE CONTAMINATION*	
(PPM)	MEASURED	FITTED
34	0.37	0.36
[illegible]	1.70	2.03
215	2.83	2.49
1180	14.36	14.90
1790	24.25	23.14

* ug per 100 cm^2

Reproducibility of Experimental Data

Reproducibility of the experimental data was assessed by performing replicate extractions of various materials from Transformer 54023 (1790 ppm) and surface swiping of core steel from a number of transformers. The data are summarised in Tables 9 and 10; values of the standard deviation (sigma) represent the total sample variability as well as analytical error. As expected, the variability in the PCB concentration (up to 42 %) was significantly greater than in the oil content measurements. Sigma values associated with surface contamination data varied up to 64 %.

TABLE 9

REPRODUCIBILITY OF SOLVENT EXTRACTION DATA - MATERIALS FROM TRANSFORMER 54023

ID	% OIL		PCB (PPM)		PCB/OIL (ug/g)	
	MEAN	SIGMA	MEAN	SIGMA	MEAN	SIGMA
PR1	24.4	2.2 (8.9%)	245	34 (14%)	1005	95 (9.5%)
PA1	15.8	1.4 (8.9%)	675	262 (39%)	4303	1794 (42%)
C1	16.3	0.7 (4.1%)	277	18 (6.3%)	1704	167 (9.8%)
W1	16.6	2.4 (14.5%)	167	56 (33%)	989	199 (20%)
PL1	6.6	0.65 (9.9%)	37	3.0 (8%)	574	105 (18%)

Compaction of Porous Material

A brief assessment of high force compaction as a means for volume reducing and decontaminating porous transformer materials was carried out using a specially designed press having a provision for collection of the expelled oil. Pressures up to 10,000 psi were imposed on samples of various materials.

Unfortunately, the quantity of oil expressed from the samples was generally much lower than previously determined by solvent extraction. The oil appears to be physically bound within the solid matrix. Sufficient oil was, however, collected to enable a determination of its PCB content. The results are given in Table 11. Also shown in the Table are the PCB/oil ratios from Tables 4-6.

The contamination level in the expressed oil generally was between 75 and 100% of the contamination in the bulk oil. The difference in the two concentrations is an indication of the adsorption of PCBs on the surfaces of the porous materials. As noted earlier, a similar conclusion could not be drawn from an examination of the PCB/oil ratios which by and large indicated little or no preferential partitioning of the PCBs in the solid phase. This anomaly may be due to experimental error: the error associated with the measurement of PCB in expressed oil is lower than that associated with measuring the PCB/oil ratio.

The results suggest that even if compaction (at higher forces) could be applied to expel all the soaked oil in the porous materials, residual PCB corresponding to the amount adsorbed would still be present in the compacted waste. Based on these findings, compaction does not appear to be a promising means for decontaminating the waste; extraction in solvent or fresh oil would probably be necessary.

TABLE 10

REPRODUCIBILITY OF SURFACE SWIPING DATA FOR CORE STEEL (M1)

PCB IN BULK OIL (PPM)	CONTAMINATION* MEAN	SIGMA
34	0.21	0.016 (7.6%)
215	2.27	1.46 (64%)
1180	5.1	1.7 (33%)
1790	12.9	8.1 (63%)

* ug/100 cm2

TABLE 11

PCB CONTAMINATION IN OIL EXPRESSED FROM VARIOUS TRANSFORMER MATERIALS

	PCB CONTAMINATION (ug/g)		
SAMPLE*	BULK OIL	EXPRESSED OIL	PCB/OIL*
PR2	215	250	270
PA4	215	215	259
PR1	1180	921	647
PA1	1180	465	3036
W1	1180	972	681
W2	1180	887	1370
PL1	1180	1131	479
PA3	1790	1715	2319

* Sample notation and data from Tables 4-6.

4.0 SUMMARY AND DISCUSSION

The distribution of PCB among various components of each transformer along with the weight distribution of the components is summarised in Table 12. While the various insulations represent 3.7 $\pm$ 0.7 % of the transformer weight, they house 94.8 $\pm$ 2.9 % of the total PCB inventory. Among the insulations, about 55 to 70 % of the inventory is associated with papers and 10 to 20 % with pressboards. The total inventory of PCBs in the transformers varied between 0.04 g for the 'uncontaminated' 34 ppm transformer to 1.04 g for the transformer with 1790 ppm contamination. These quantities exclude the PCBs associated with the oil pool found at the bottom of the casings. Accounting for the latter increases the total inventory in the 'as received' transformers by up to 70 wt %.

It is reasonable to seek a correlation between the bulk oil contamination level (ug/g) and the overall contamination level (ug/g) of the porous insulation. Note, however, that the variability in the weight % and PCB % of the porous insulation is relatively small despite the fact that the transformers examined differed in several respects: year of manufacture, manufacturer, volume and kVA rating. Because of this, one can also expect a correlation to exist between the bulk oil contamination level and the overall contamination level expressed as micrograms PCB per weight in grams of the undismantled drained transformer.

TABLE 12

INVENTORY OF PCBs IN TRANSFORMERS INVESTIGATED - SUMMARY OF RESULTS

	TRANSFORMER 80030-55 (34 PPM)		TRANSFORMER 5612-43 (177 PPM)		TRANSFORMER 705263 (215 PPM)		TRANSFORMER 54252 (1180 PPM)		TRANSFORMER 54023 (1790 PPM)	
MATERIAL	Wt.%	PCB%	Wt.%	PCB %	Wt.%	PCB %	Wt.%	PCB %	Wt.%	PCB %
CORE METALS	56.9	2.5	60.6	0.5	40.8	3.9	37.9	1.8	32.6	2.5
COPPER WINDINGS	7.5	2.0	5.4	0.3	4.9	0.2	21.4	2.9	22.4	5.5
OTHER CORE METALS	9.6	1.8	10.5	0.1	4.1	0.0	3.3	0.2	3.4	0.2
CASING	14.9	0.1	13.2	0.0	26.1	0.1	21.3	0.2	27.6	0.7
LID	2.8		2.7		4.2	0.0	2.9	0.0	2.6	0.0
PRESSBOARD	0.8	22.5	0.8	21.1	1.0	19.7	0.9	10.8	0.8	9.1
PAPERS	2.5	65.5	2.0	71.3	2.0	61.8	2.2	57.2	1.9	56.2
CLOTH	0.1	5.4	0.1	6.4	0.1	6.3	0.2	2.4	0.1	2.7
RUBBERS	0.0	0.0		0.0	0.3	8.0	0.0	0.0	0.0	0.0
WOOD	0.0	0.0		0.0	0.0	0.0	1.0	23.0	0.9	21.6
PLASTICS	0.0	0.0		0.0	0.0	0.0	0.3	1.4	0.3	1.3
MISCELLANEOUS	5.0	0.2	4.8	0.3	9.5	0.0	8.6	0.0	7.5	0.0
NONPOROUS MATERIALS	96.6	6.6	97.1	1.2	96.6	4.2	95.4	5.2	96.0	9.1
POROUS MATERIALS	3.4	93.4	2.9	98.8	3.4	95.8	4.6	94.8	4.0	90.9
TOTAL WEIGHT (KG)		125		203		57		62.4		72.5
TOTAL PCB (g)		0.043		0.28		0.145		0.58		1.04
TOTAL METAL SURFACE (m^2)		92		20		21		28		28
OIL POOL (Kg)		0.71		0.71		0.15		0		0.40
PCB IN OIL POOL (g)		0.024		0.13		0.033		0		0.71

An excellent correlation is in fact obtained as shown in Figure 2. Thus the PCB present in a drained transformer can readily be estimated provided the weight of the transformer and the bulk oil contamination level are known.

Figure 2 also shows the data reported in Reference 8 (the PCB in the drained transformer was calculated from their 'Residue' data in Table 2-3 while the weight of the drained transformer was determined from the difference in the total weight and weight of oil in Table 2-1). It is interesting to note the similar linearity in the data from this reference as obtained in this study. However, their data indicates a significantly higher inventory. Since linearity is observed in both studies, differences in the types of the transformers autopsied are probably not a factor. Also, the experimental procedures in both studies were very similar. The most probable explanation may be the extent of oil drainage. In the present

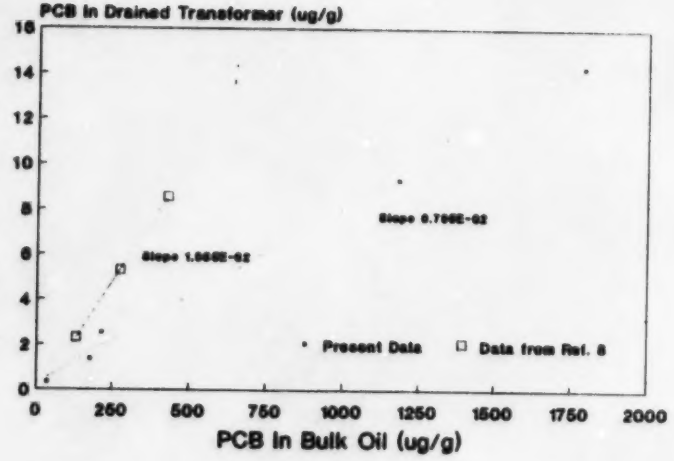


Figure 2 PCB Inventory in Pole Top Transformers

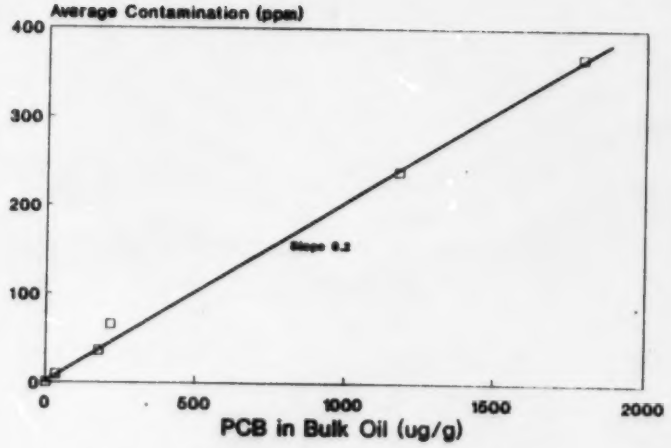


Figure 3 Avrg Contamination in Porous Materials

study, the transformers had been drained and transported several days prior to being autopsied. In the EPRI study, however, the transformers were drained just prior to being dismantled.

The average contamination in the porous materials as a function of bulk oil contamination level is shown in Figure 3 and is linear. The average contamination was calculated by attributing to the porous materials 3.7 % of the total transformer weight and 94.8 % of the total PCBs present. According to Figure 3, the fluid level could be as high as 245 ppm without the average contamination in the porous materials exceeding the 50 ppm regulatory limit. Thus porous materials dismantled from transformers with less than 245 ppm contamination in the oil constitute a non-PCB waste.

The surface contamination levels reported in the preceding tables assume the swiping efficiency to be unity (100%), i.e., the swiping transfers all the PCB contaminant from the surface on to the wet Kimwipes. This assumption was assessed by depositing controlled aliquots of isooctane solution containing Aroclor 1242 on rigorously cleaned core steel surfaces (from the 34 ppm transformer) and then allowing them to dry in air. The surfaces were then swiped as before (three successive swipes) and followed by extraction of the Kimwipes in isooctane. To minimise experimental error, the amount of PCB deposited was much higher than levels previously determined on the dismantled transformer surfaces. The levels ranged between 236 and 627 ug/cm^2. An overall swiping efficiency was calculated as the ratio of PCB extracted (note that PCBs on Kimwipes were readily extracted in isooctane, i.e., this step essentially had a 100 % efficiency) to the PCB deposited. The measured efficiency was 0.570 $\pm$ 0.057 and showed within the range investigated no dependence on the level of surface contamination.

A swiping efficiency significantly lower than 1.0 will to some extent distort the overall distribution of PCBs between the porous insulation and the nonporous surfaces. Of more serious concern is the potential release of contaminated metal which may be above the generally accepted guideline of 10 ug/100 cm^2 and the associated liability.

5.0 CONCLUSIONS

1. While the various porous insulations represent 3.7 $\pm$ 0.7 % of the transformer weight, they house 94.8 $\pm$ 2.9 % of the total PCB inventory; the remaining inventory is associated with the non-porous metallic surfaces. About 55 to 70 % of the inventory is associated with papers and 10 to 20 % with pressboards.

2. The total inventory of PCBs in the pole top transformers is essentially a function of the initial oil contamination level and the quantity of porous material present. Since the latter is a relatively constant weight fraction of the transformer weight, the inventory is alternately a function of the drained weight of a transformer. The inventory in grams can be calculated as 0.795E-05 * Oil contamination (ug/g) * Weight of Drained Transformer (Kg).

3. The average contamination in the porous materials was linearly related to the bulk oil contamination level. According to this relationship porous materials dismantled from transformers with less than 245 ppm bulk oil contamination would constitute a non-PCB waste, i.e. less than 50 ppm contamination. This could be the basis for requesting MOE to allow the continuation of the current decontamination practice for transformers with fluid contamination levels up to about 250 ppm; those above this level would require decontamination to reduce the PCB content of porous materials below 50 ppm.

4. Swiping efficiencies must be taken in to account in determining surface contamination level. If the efficiencies for the various materials are significantly lower than 100 %, as observed in the case of core steel, then the overall PCB distribution in the porous materials determined here is somewhat overestimated.

5. The average contamination level (ug/100cm^2) on transformer steel surfaces (excluding the lid and bottom of casing) can be estimated from the relationship 8.71 10^{-3} * $C_b^{1.05}$ where C_b denotes the bulk oil contamination (ug/g) level. This relationship does not take swiping efficiency in to account. According to the relationship, a surface contamination level of 10 ug/100 cm^2 corresponds to a fluid contamination level of about 800 ppm.

6. The contamination levels on casing surfaces is greatest at the bottom.

7. Compaction does not appear to be a viable means for decontaminating the waste; extraction of the PCB in solvent or fresh oil is required.

6.0 RECOMMENDATIONS

1. Figure 2 is recommended for determining the inventory of PCBs in pole top transformers.

2. MOE should be requested to allow the continuation of the current decontamination practice for transformers with fluid contamination levels up to about 250 ppm since these do not contain porous materials exceeding an average contamination level of 50 ppm.

3. Swiping efficiencies for various transformer metallic surfaces should be determined. These should be taken in to account in the determination of surface contamination levels.

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